ANALOG DEVICES

AN-251
APPLICATION NOTE

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R_{ON} Modulation in CMOS Switches and Multiplexers; What It Is and How to Predict Its Effect on Signal Distortion

by John Wynne

A single CMOS switch or a single channel of a CMOS multiplexer essentially consists of an N-channel and a P-channel MOSFET transistor in parallel, see Figure 1a. The respective drains and sources of the two transistors are tied together to become the switch terminals while the gates of the two transistors are usually driven with the power supply voltages, V_{DD} and V_{SS}, to control the on-off action of the switch. Essentially the N-channel is ON for positive gate-to-source voltages and OFF for negative gate-to-source voltages (vice versa for the P-channel).

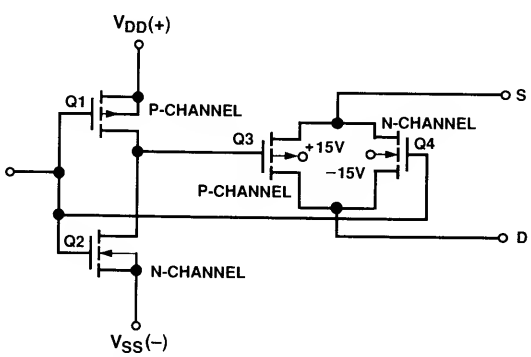

Figure 1a. Basic CMOS Switch

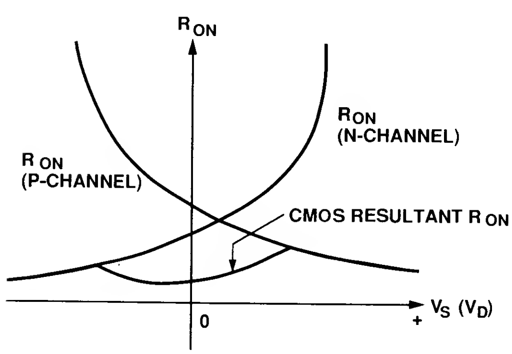

Figure 1b. Individual MOSFET R_{ON} Profiles vs. V_S (V_D)

With a fixed voltage on the gate, the effective drive voltage for either transistor varies in proportion to the polarity and magnitude of the signal passing through the switch. In Figure 1b where R_{ON} is plotted against applied switch voltage V_S (V_D), the resistance of the N-channel increases with positive voltage and the resistance of the P-channel increases with negative voltage. The resultant parallel combination (heavy line) exhibits the well-known "crown" or twin-peak characteristic. This variation in on-channel resistance with input signal is known as R_{ON} modulation.

Figures 2 and 3 show some typical R_{ON} and ΔR_{ON} profiles for Analog Devices' ADG5XXA multiplexer series. Figure 2 shows R_{ON} for three different power supply voltages. Figure 3 shows an expanded view of the change in resistance (ΔR_{ON}) under the same conditions. Note that both R_{ON} and ΔR_{ON} increase as the power supplies are reduced.

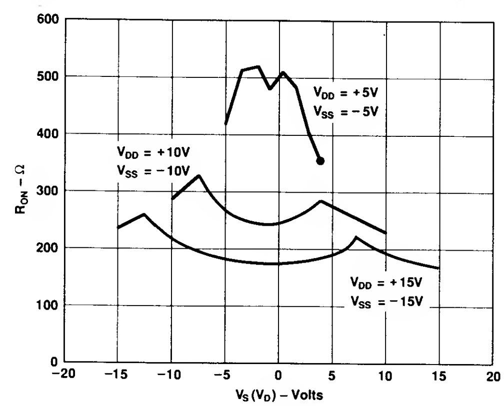

Figure 2. R_{ON} as a Function of V_S (V_D), T_A = +25°C

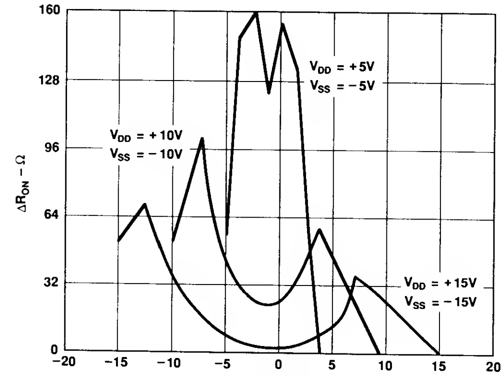

Figure 3. ΔR_{ON} as a Function of V_S (V_D), T_A = +25°C

R_{ON} modulation can be reduced by restricting the input signal range through the switch. For instance, for the ADG5XXA multiplexer series operating on ± 15 V power supplies, ΔR_{ON} is less than 4 Ω over an input signal range of ± 3 V, increasing to 12 Ω with a ± 5 V input signal range and increasing again to over 30 Ω with a ± 7 V input signal range. Configuring a switch or multiplexer to operate directly into the virtual earth of an op amp obviously ensures a very low voltage across the channel which in turn virtually eliminates R_{ON} modulation problems. However, many applications require high level signals to be passed through the channel. Figure 4 shows a typical situation where high level signals are multiplexed into a load resistance R_L.

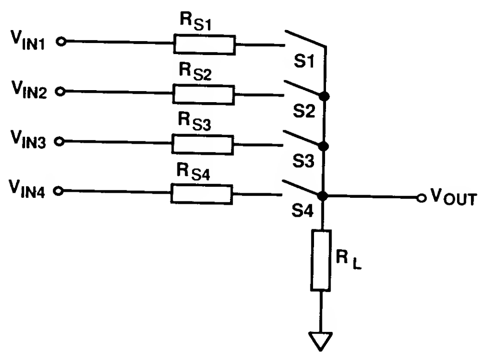

Figure 4. Multiplexing High Level Signals

In addition to the common load resistance, each multiplexer channel has a source resistance R_{SN} in series with it. Over the signal range of interest, the amount of distortion generated by R_{ON} modulation is proportional to the ratio of maximum to minimum channel resistance, i.e.,

$$\text{Distortion} \propto \Delta R_{ON}/(R_{EXT} + R_{ON}\ min)$$

The external resistance R_{EXT} is the sum of source and load resistance. For a given multiplexer (i.e., given R_{ON} minimum and ΔR_{ON}) , making the external series resistance large reduces the generated distortion through the channel. However, high resistor values result in high levels of circuit noise, so a compromise must be made when deciding on values for the external resistors.

PREDICT DISTORTION GRAPHICALLY

Figure 5 shows a nomograph which can be used to quickly predict, to a first order, the distortion generated by a single multiplexer channel in series with an external resistor. The nomograph scaling is based upon Figure 4. The left most scale represents the total channel resistance including the switch R_{ON} value at V_S (V_D) = 0 V. The middle scale represents distortion, and the right most scale represents ΔR_{ON}, the change in R_{ON} *over the signal range of interest.* The nomograph is used by drawing a straight line between the appropriate points on the outer scales; where the straight line intersects with the middle scale yields the predicted distortion. As an example of its use, consider a switch with R_{ON} = 400 Ω at V_S (V_D) = 0 V and ΔR_{ON} = 60 Ω over the input signal range. With R_S = 0 Ω and R_L = 4 kΩ, the total harmonic distortion (THD) through the channel is approximately 0.3% or −50 dB. With R_L = 40 kΩ, the THD improves to 0.048% or −66 dB.

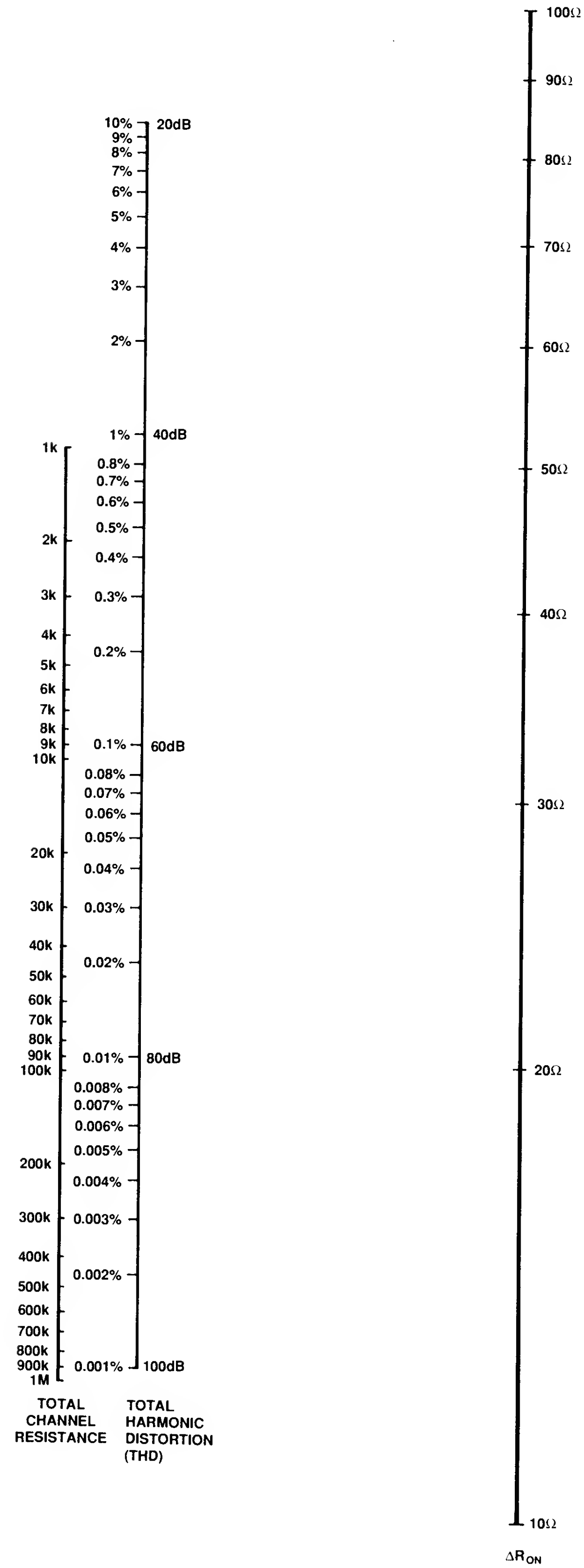

Figure 5. Nomograph to Determine THD Through a Single Switch or Multiplexer Channel